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Performance Analysis of a ZVS Parallel Quasi Resonant Converter for a Solar Based Induction Cooking System

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ABSTRACT— *This paper aims to analyse the behaviour of a parallel quasi resonant converter for a proposed solar based induction cooking system under ZVS condition. The IGBT incorporated in the resonant converter will switch as a self oscillating circuit and operate under ZVS condition to minimize switching losses. The resonant converter simulation design responds to different equivalent pan resistances and it can be said that the equivalent pan resistance of 5Ω will provide the maximum efficiency of the system at a resonant frequency of 20KHz. The resonant frequency can be varied by changing the duty cycle parameter in the control part of the design for a range of 14KHz ~ 33KHz. The output power of the cooking pan is seen to vary for different pan resistances to obtain an effciency of the system that varies within the range of 75% ~ 93%. The resonant converter was designed and analysed in PSIM software to show these analysis.*
Keywords— *Solar Energy, Induction Heating, Zero Voltage Switching (ZVS), Quasi Resonant Converter, IGBT*

I. INTRODUCTION

The main fuel for generating electricity in Bangladesh is natural gas which is also used for the cooking purpose. Due to the growing population, the depletion of natural reserve is seen to be a threat to provide the domestic needs of the citizens residing in this country [1]. To reduce the stress on the natural gas reserve, cookers are now being used that run on electricity such as induction cookers. However, due to the unavailability of electricity and lack of gas supply, cooking is now a major concern. The only possible solution to lighten up the crucial situation is the use of renewable energy. There are various forms of renewable energy such as solar, wind, tidal, biogas, hydro and geothermal energies. Due to the geographical location of Bangladesh which is 88.04 and 92.44 degrees east and 20.30 and 26.38 degrees north latitude it becomes an ideal location for solar energy utilisation. An average solar radiation of 4-6.5kWhm^{-2}day^{-1} can be attained and radiation is seen to be maximum for seven months March- September which makes solar energy the optimum choice as thesustainableenergysourceofBangladesh[2].The photovoltaic technology used in the solar cells are capable to provide electrical energy which makes the foundation to use this vital energy source for the cooking system in Bangladesh [3]. The solar panels that are to be used in our design will provide a DC input voltage to the cooker. Induction cooking is based on Induction Heating technology which provides a clean, safe, highly energy efficient, pollution-free and a very fast heating system [4]. The operating principle of Induction heating is such that a very high frequency AC current flows through the induction coil which creates a high alternating magnetic field and induces a current in the cooking pan placed on top of the coil [5]. There are a number of factors on which the frequency of inductor current is dependent such as: penetration depth, size of the induction coil and electromagnetic coupling [6]. An IGBT based parallel quasi resonant converter has been proposed and designed in this paper for induction cooking. The block diagram of the proposed solar based induction cooking system is shown in Fig. 1 and the function of each component is explainedbelow.

Fig.1. Proposed Solar Induction Cooking System

A. SolarInput

This paper proposes the design of an induction cooker using a solar dc input where 20 thin film solar panels (KANEKA U- EA100) are used with a specified series-parallel combination of 5 panels being connected in a series configuration, each series connection providing 475W, and each of these series connection connected in four parallel branches to provide 2KW(approx.) of input power to the system [3]. This combination is being set in order to keep the input voltage stable within the range of 220V~250V at different solar irradiation levels. The specifications of the panels being used are shown in Table1.

TABLEI. PSIM THIN FILM MODULESPECIFICATIONS

Parameter	**Specifications**
Number of cells	106
Open Circuit Voltage (V_{OC})	71V
Short Circuit Current (I_{SC})	2.25A
Voltage at Maximum Power (V_{pm})	53.5V
Current at Maximum Power (I_{pm})	1.78A
Maximum Power (P_{max})	95W

B. Inverter

An inverter plays a key role by converting the DC current into a high frequency AC current to the heating induction coil. The choice of IGBT for the simulation design used in this paper over other semiconductor devices is because of its lower switching loss and fast switching speed [6]. Zero Voltage Switching (ZVS) is used to minimize the switching loss by setting the voltage of the switching circuit to zero right before the circuit is turned on. As a result less EMI is produced at high frequency [7]. The main reason for choosing a parallel quasi resonant converter for the design of the inverter other than the existing topologies such as half bridge series resonant topology and full bridge resonant topology, is its single switching circuit which makes the design simple and smaller for PCB and heat sink.

C. Operating principle of Parallel Quasi ResonantConverter

The equivalent circuit model of a parallel quasi resonant converter is shown in Fig. 2 where the load is represented by the equivalent pan resistance R^* in Fig. 2(c) [8].

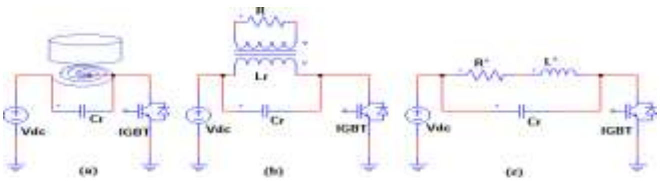

Fig. 2. Equivalent circuit model of a Parallel Quasi Resonant Converter

There are four main modes of operation for one switching cycle of the parallel quasi resonant converter which is shown in Fig. 3 [4,6]. The modes are explained below where L_r and C_r denotes the resonant inductor and resonant capacitor respectively and the equivalent pan resistance is represented byR.

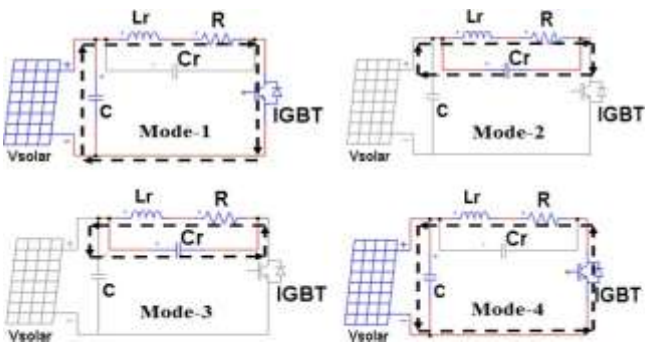

Fig. 3. Modes of Operation of an equivalent circuit model

In Mode-1, when the switch is on the current flows from L_r to the switch and in Mode-2 when the switch is off, the current flows from L_r to C_r. In mode-3, the current starts to flow in opposite direction from C_r to L_r as the current through L_r becomes zero. In mode-4, the diode will be forward biased and the current will now flow through C and diode toL_r.
The design parameters of the parallel quasi resonant converter is listed in Table 2.

TABLEII. DESIGN PARAMETERS OF PARALLEL QUASI RESONANTCONVERTER

Parameter	**Specifications**
V_{in}(solar)	200V~250V DC
Inductance Coil (L_r)	90uH
Capacitor (C_r)	0.3uF
Capacitor (C)	330uF
Load resistance	5 Ω

D. ResonantFrequency

A resonant circuit consists of an inductor, capacitor and a resistor where the energy transfer between an inductor and capacitor occurs [7]. The speed with which the energy is transferred is defined as the resonant frequency which is calculated by the equation below:

$f=1/2\pi\sqrt{L_rC_r}$ (1)

II. PSIMDESIGN

The schematic design of the solar fed ZVS parallel quasi resonant converter is shown in Fig. 4. The solar panels of power 2KW is fed as the input to the inverter. In an induction cooking system, the values of L_r and $C_r$would be fixed but as the load to the cooker is the cooking pan, it may vary in different sizes. This indicates that the change in pan resistances in the equivalent circuit model of the cooker can be one of the performance parameters of the system. By changing the resistance values the performance of this design is analysed in PSIM software and results discussed in later sections.

A. CircuitDescription

A capacitor of 330uF is placed at the input of the induction coil so that it can supply the peak resonant current to the L_r as shown in Mode-4 when the IGBT is off and diode is on. The solar DC input voltage which is labelled as V_{in} is compared with the voltage across the switch labelled as V_{switch} in order to start up a switching cycle. At any moment of time, when V_{switch} will be higher than V_{in} the switching will start. Direct connections of these voltages to the comparator will not be wise as such high voltage may burn out the switch. Thus, resistors of large values and a capacitor of 330pF is placed in between the input terminals of the COMP1 to decrease V_{switch}. Now, when V_{switch} is compared with the V_{in}, the output pulse of COMP1 is a thin-width pulse. This pulse is then fed to the falling edge of a monostable oscillator of 10us fixed pulse width to allow the resonant circuit to complete all the four modes of operation. The pulse from the monostable oscillator is then fed to a control circuit which has a simple npn transistor connected to a R-C circuit. The resistor R_0 begins to charge up the capacitor C_0which then creates a sawtooth waveform and is then fed to the inverting terminal of the second comparator COMP2. Using trial and errormethod

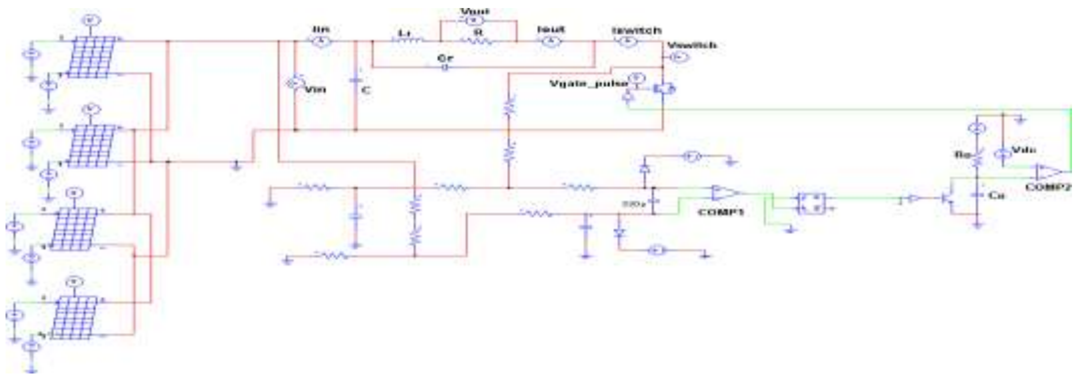

Fig. 4. Schematic design of the proposed solar induction cooking system

values of R_0 and C_0 are chosen to obtain a proper sawtooth. A DC voltage labelled as $V_{dc}$is then applied to the non-inverting terminal of the COMP2. The output of COMP2 will be high when V_{dc} voltage is above the sawtooth and later will be low when V_{dc} voltage is below the sawtooth. This means the on- time of the pulse can be varied by changing V_{dc} which gives us the control to vary the duty cycle. At the end, this output pulse is fed to the IGBT gate so that the switching frequency is the same as resonantfrequency.

B. Resonant Converter OutputWaveforms

The output waveforms of the parallel quasi resonant converter are shown in Fig. 5(a) and 5(b) which clearly represent the ZVS condition marked with red dotted lines. Under the ZVS condition, when the voltage of the switch reaches zero, the switch is turned on. During the turn-on of the IGBT switch, the inductor coil current reaches its peak value. These simulations have been obtained using the PSIM software and are shownbelow.

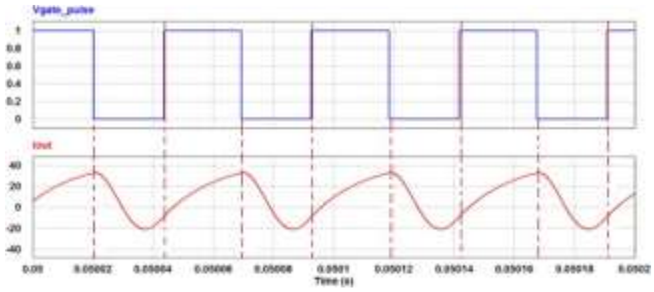

Fig. 5.(a(IGBT gate pulse and load current waveforms under ZVS condition

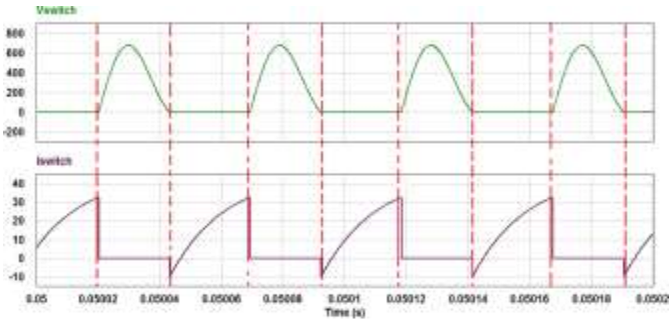

Fig. 5.(b) Switch voltage and switch current waveforms under ZVS condition

III. PERFORMANCEANALYSIS

The performance of the proposed solar based induction cooking system was analysed by varying the duty cycle of the IGBT pulse and changing the equivalent pan resistances**.** Fig. 6 shows the graph where the duty cycle is varied by changing the V_{dc} labelled in Fig. 4, which can change the resonant frequency within a range of 14KHz to 33KHz for different cooking pan resistancevalues.

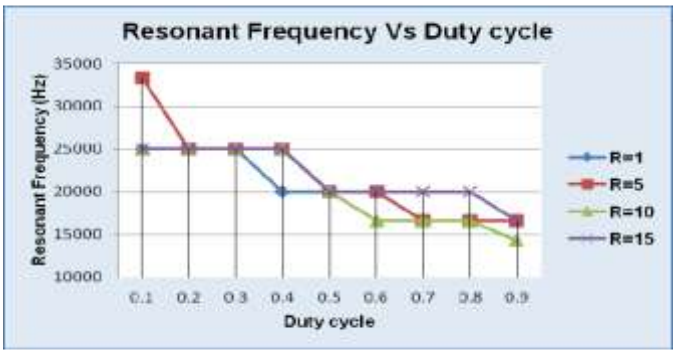

Fig. 6. Resonant Frequency Vs. Duty cycle for various pan resistance

From the graph in Fig. 7, it can be seen that as the duty cycle is increased, the efficiency of the system increases for all the selected values of pan resistances. It can be clearly stated that, the efficiency of the system can be achieved to be 95% at maximum solar irradiation level for R=5Ω. Efficiency is calculated using the followingequation:

$\eta=(P_{out}/P_{in}) \times 100\%$ (2)

Fig. 7. Efficiency Vs Duty Cycle for different pan resistance

Fig. 8 shows that the maximum output power can be achieved at the maximum solar irradiation level (i.e. 1000) for all the selected equivalent pan resisitance values for 50% duty cycle. It is also seen that the change in resistance values have no direct effect on the resonant frequency which remains fixed at 20KHz.

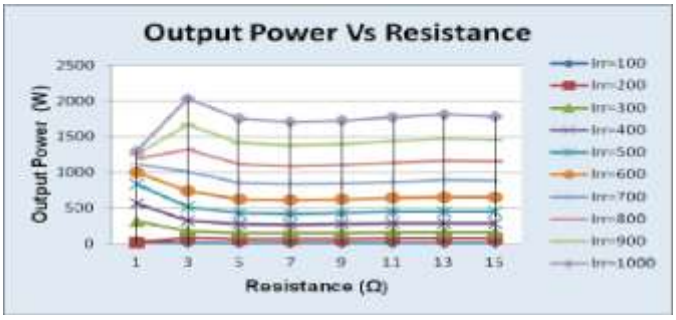

Fig. 8. Output Power Vs Equivalent pan resistance at different solar irradiationlevels

Fig. 9 shows that the selected equivalent pan resistance values can provide an efficiency of the system to be above 75%. From Fig. 9, it can be stated that, the efficiency of the solar induction cooking system can be achieved to be maximum of 93% when R=5Ω at maximum solar irradiationlevel.

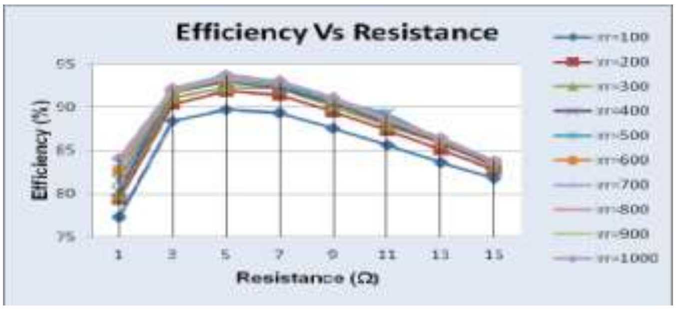

Fig. 9. Efficiency Vs. Equivalent pan resistance at different solar irradiation levels

The change of output power for the equivalent pan resistance of R=5Ω at different irradiation levels is represented in Fig. 10 by changing the duty cycle parameter. From Fig. 7 it can be seen that maximum output power of 2130W can be achieved at the maximum solar irradiation level and the efficiency of the system will be above90%.

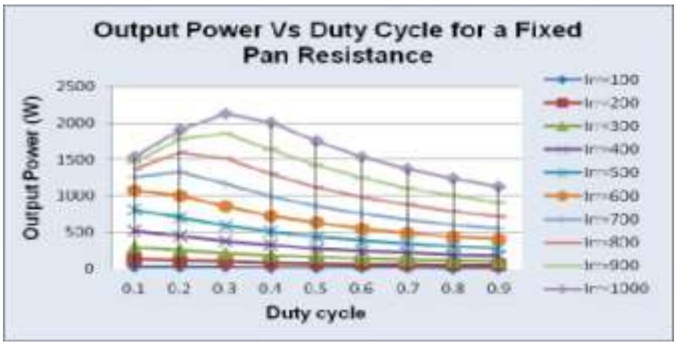

Fig. 10. Output Power Vs. Duty Cycle at different solar irradiation levels

From Fig. 6 and 7, it is seen that the equivalent pan resistance of R=5Ω has a high efficiency for different duty cycle providing a range of resonant frequency. Also, from Fig. 8 and 9, it can be seen that at different solar irradiation level, the performance of R=5Ω is optimum. Added to this, the performance of this equivalent pan resistance is shown in Fig. 10 from which it can be seen that output power obtained in the pan at different irradiation levels can be tracked by the duty cycle parameter. Thereby, the proposed induction cooking system will provide the most efficient performance for equivalent pan resistance of 5Ω.

IV. CONCLUSION

In Bangladesh, consumers are heavily dependent on the foreign technology which makes it difficult for troubleshooting when the products need repair or disfunction. The parallel quasi resonant converter designed in this paper for the proposed solar based induction cooking system is made with all the local components available which will make it compact in size, cheap and the fixation will be easy. The proposed system will use solar energy as the input to the cooker to reduce the burden on the natural gas supply as solar energy has a good prospect to harness solar power in Bangladesh. In the coming years, the price of solar panels will reduce further and make it more economically viable for the consumers. The resonant frequency of the designed parallel quasi resonant converter can be varied between 14KHz to 33KHz by changing the duty cycle. From the analysis, it can be seen that, at a duty cycle of 50%, the equivalent pan resistance of 5Ω attains a fixed resonant frequency of 20KHz at all solar irradiation levels and has the maximum efficiency of 93%. Thus, it can be said that a parallel quasi resonant inverter can be highly efficient and effective for the use of induction cooking and can be utilised as a convenient alternative for cooking purposes inBangladesh.

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